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THE RHIZOCTONIA DISEASE OF POTATOES

W. J. Morse & M. Shapovalov

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BULLETIN 230.

THE RHIZOCTONIA DISEASE OF POTATOES.

W. J. Morse and M. Shapovalov.

The fungus formerly known as *Rhizoctonia solani* Kühn, more recently as *Corticium vagum* var. *solani* Burt and considered by some writers as identical with *Hypochnus solani* P. & D. is a common inhabitant of New England potato soils. In fact its occurrence is so universal that it is practically impossible in most localities in this part of the country, with which the writers are familiar, to examine a barrel of potatoes without finding from a few to many tubers carrying at least some sclerotia of the Rhizoctonia stage of the fungus. Fig. 61 shows a potato so affected. Every housewife who prepares potatoes for the table is familiar with the fungus in this form, but the sclerotia are commonly considered to be closely adhering particles of black soil which for some reason are difficult to wash off from the surface of the potato. The fact that these hard, brownish or black, often flattened, closely appressed bodies, which vary greatly in size and shape, are made up of closely interwoven threads of a fungus which serve as a means of carrying this fungus over winter and of distributing it from place to place, is not generally understood by those who grow potatoes or prepare them for the table.

While the appearance of such potatoes is affected and extra labor is required to wash them, the sclerotia are entirely superficial and not even the skin of the tuber is injured. Although Rhizoctonia has been classed as an active parasite of the potato in some localities in this and other countries the senior writer has, in the past, shared the opinion of certain other students of the subject with whom he has conferred that it is not an important factor in the production of potato diseases in New England. Work which we have done and observations which

we have made recently in Maine, particularly during the past year, however, lead us to the conclusion that a more extended study of the subject will show that this position is by no means in accord with the facts. The significance of these observations and of the results of the experiments here reported is more evident when the latter are considered in connection with some of the previous work in this country upon the parasitism of the same fungus or closely related species. No attempt is made, however, to review the literature upon Rhizoctonia as a whole.

Previous Studies in America upon Plant Diseases Caused by Rhizoctonia.

The first important report on the economic aspects of Rhizoctonia in America is that of Pammel (10) in 1891, who studied a beet root-rot in Iowa which he stated was caused by *Rhizoctonia betae* Kühn (*R. solani* Kühn). The following year Atkinson (1) published the details of certain studies and experiments in which he showed conclusively that a sterile fungus was the cause of "sore-shin" or damping off of cotton in Alabama. Later, in 1905, the same writer (2) found a similar parasite causing a damping off of beans, lettuce, radishes, egg plants and cabbages in New York. Duggar (4) in 1899 reports Rhizoctonia as the cause of beet root-rot in New York and also as producing a damping off of beet seedlings, lettuce, beans, radishes, cucumbers and occasionally many other seedlings, as well as a crown rot of radishes.

A very important contribution to the literature upon Rhizoctonia as a cause of plant diseases in America is that of Duggar and Stewart (5, 6) which appeared in 1901. They showed that this fungus attacks a large number of different hosts, including some 30 species of cultivated plants in the United States. Their conclusions regarding its parasitism are briefly stated in the following paragraph quoted from the summary:

"Rhizoctonia is the cause of a destructive root-rot of the sugar beet, a destructive stem-rot of the carnation, a leaf-rot of greenhouse lettuce, a leaf-rot of ornamental asparagus, and a root-rot of the carrot; and is of common occurrence on the stems and tubers of the potato. It is a frequent cause of damping-off of various seedling plants, such as beet, carnation, celery, lettuce, cabbage, etc. It is also the suspected cause of disease in the bean, rhubarb, cotton and some other plants. Further observations will probably show that many other plants are infested by it."

Speaking specifically regarding Rhizoctonia on the potato they mention the fact that while a disease caused by *Rhizoctonia solani* Kühn has long been common in Germany and known under the name of "Grind" or "Pockenkrankheit" so far as they have been able to ascertain there was no record of the occurrence of the fungus as a parasite upon the potato in America. Their observations did show that potatoes in the United States may be quite generally infested by a species of

Rhizoctonia. Their discussion leads the reader to infer that at that time they considered this occurrence of the fungus on the potato in this country as of minor economic importance. However, they mention one instance observed by Mr. F. M. Rolfs where there was good evidence that the fungus killed a considerable number of potato plants.

Rolfs (11), working in Colorado in 1902, was the first to demonstrate conclusively that Rhizoctonia may be responsible for a serious disease of the potato in the United States. The importance of this and a later publication (12), as bearing upon potato diseases in other parts of the country, apparently has not been fully appreciated by American phytopathologists. This is doubtless due to the fact that they felt that in the irrigated districts of Colorado Rolfs was working under conditions somewhat dissimilar to those which obtain in other potato growing sections and, therefore, would be liable to encounter difficulties which would not be expected elsewhere.

The first publication was simply a preliminary report in which he points out some of the important characteristics of the disease and presents certain evidence tending to show that Rhizoctonia is the cause of conditions observed. It does, however, contain many observations which he was able to confirm later, and which the present writers have been able to duplicate in Maine under decidedly different conditions with regard to soil and moisture. Cases are reported where the plants were apparently thrifty and gave promise of an abundant yield, but at harvest time only a few potatoes were found in a hill. Less frequently the plants set an abnormally large number of tubers and these were small and clustered near the surface of the ground, giving rise to the term "Little potato disease." Another characteristic was the formation of aerial tubers or the production of green, tuber-like out-growths in the axils of the leaves and branches above ground. The author claimed that these conditions resulted from the attacks of the fungus upon the parts of the plants below ground. He also stated that the young plants were often severely injured or even killed before they reached the surface.

In the second report already mentioned Rolfs gives the results of additional studies upon the life history of the fungus, the nature of the injuries upon the host, factors concerned in the spread and propagation of the disease, methods of control, etc. Perhaps the most important contribution made in this paper was the publication of the discovery of the Corticium or fruiting stage of the fungus.

Laboratory studies showed that to grow best the fungus required plenty of moisture and a temperature equivalent to that which is experienced out of doors in mid-summer. Likewise, according to Rolfs experience, the disease was more virulent where the ground was wet and soggy. This taken in connection with other field observations led him to suggest that over-watering the plants in the irrigated districts materially increased the severity of the attacks of the fungus.

As regards preventive measures Rolfs found that treating the seed with corrosive sublimate gave marked gains where the crop was raised

in new ground. Less favorable results were obtained with formaldehyde, and neither coating the seed with sulphur nor applying lime to the soil at the rate of 3,000 pounds per acre produced any apparent beneficial effect.

About the same time that Rolfs was working on the Rhizoctonia disease of the potato in Colorado, Selby (13) was making similar studies in Ohio. Selby was attracted by certain above-ground signs of disease of potato plants in various parts of that state. He states that for at least 3 years previous to the publication of his paper complaints had been received of the early dying of potato plants, apparently from some disease below ground, before the formation of many tubers. A prominent characteristic of the affected plants was an excessive branching and in general a conspicuous clustering of these branches or of the terminal leaf groups. This condition or appearance he designated as "Potato Rosette." While recognizing that other below ground injuries of the stem might produce similar effects on the tops he was satisfied that the rosette appearance of the foliage was associated with or a secondary effect of the attacks of the Rhizoctonia fungus on the parts of the plants below ground similar to those described by Rolfs.

Selby also carried on experiments to test seed disinfection as a means of preventing the disease. These, apparently conducted on a smaller scale, gave quite different results from those obtained by Rolfs with regard to the relative efficiency of corrosive sublimate and formaldehyde as is indicated by the following quotation:*

"The warranted conclusion, drawn from the tests of two seasons with formalin and the extended work of many seasons at the Station with corrosive sublimate seed treatment appears to be that the corrosive sublimate seed treatment does not prevent the rhizoctonia disease to any appreciable extent, while the formalin seed treatment, as shown conspicuously by the study of the growing plants and usually in the yields of tubers, does prevent the disease to a very marked extent."

Clinton (3) in 1904 mentions the occurrence of the fungus on potatoes in Connecticut. After examining several potato fields he says: "Apparently the plants did not suffer so severely from the fungus as some writers claim elsewhere. However, the relative injury caused here by the fungus is a subject which needs further attention, since the parts attacked occurring under ground the injury and cause may easily escape notice."

Orton (9) in 1909 states that Rhizoctonia causes a stem blight of potatoes and a surface cracking or russeting of the tubers in heavy western soils, particularly San Joaquin County, California.

Güssow, the Dominion Botanist of Canada, in his report of 1912 (8) gives a summary of the important characteristics of the Rhizoctonia disease of the potato but does not state where or to what extent it occurs in Canada, in conversation with the senior writer after the above was written Prof. Güssow stated that the disease is common in various

* p. 58.

parts of Canada, producing injuries on the growing stems similar to those observed in Maine. He does state that in his experience the fruiting stage of the fungus is not abundant but some good specimens have been obtained from British Columbia and Alberta.

An experiment where seed tubers bearing numerous sclerotia of the fungus were soaked in corrosive sublimate and formaldehyde and then planted at the Central Experimental Farm is described. Judging from the numbers of sclerotia observed on the crop in the fall, corrosive sublimate, used at one-half the strength usually employed, was decidedly more efficient than formaldehyde. The crop obtained where the former was used was practically clean while that produced where the formaldehyde treated seed tubers were planted was almost as badly covered with sclerotia as the original lot of potatoes used for seed.

Recently Gloyer (7) has made a comparative study of the efficiency of formaldehyde solution, formaldehyde gas, and corrosive sublimate for disinfecting seed tubers affected with Rhizoctonia. His conclusions were that neither formaldehyde gas nor formaldehyde solution can be depended upon to kill all of the Rhizoctonia sclerotia but, "The standard corrosive sublimate treatment is thoroughly efficient. Even with a 1 to 2,000 solution (half standard strength) all Rhizoctonia sclerotia are killed."

Rhizoctonia as a Cause of Potato Disease in Maine.

As has already been pointed out, potatoes in Maine, in common with the rest of New England and apparently many other parts of the United States, frequently show the so-called "black scurf" or the sclerotia of the Rhizoctonia fungus upon their surfaces. In fact the fungus is common and widespread in the State and probably does not cause a great amount of damage except to certain varieties of potatoes and in certain types of soil. However, complaints have been received from time to time, more especially from the southern and central portions of the State, regarding poor and uneven stands of potatoes, unexpected low yields, sometimes associated with "early ripening" or death of the tops from no apaprent cause but resembling an abnormally early maturity. Undoubtedly these various troubles result from a variety of causes, depending upon the conditions. Some of these the writers have recognized for a number of years, but the fact that Rhizoctonia is a factor, and often a very important factor in the production of certain of the conditions mentioned has been largely overlooked until recently.

Ever since Highmoor Farm in Monmouth came under the control of this Station several acres of potatoes have been

grown each year up to the present. The Green Mountain, a late variety, has produced some large and very satisfactory crops on this farm, even in relatively dry seasons.

There is at present a large and constantly growing demand for Maine grown seed potatoes of early varieties like the Irish Cobbler for southern planting. Much trouble has been experienced in the past in getting a sufficient supply of this seed stock which is free from the germs of blackleg and which does not contain mixtures of late varieties like the Green Mountain. It has been maintained at this Station that these difficulties could be overcome by a little careful work and that once the Irish Cobbler seed was freed from mixtures and blackleg it could be kept pure at practically no expense. Largely for this reason a change was made to the early variety for the main crop on the farm and the results obtained as far as the original object was concerned were entirely satisfactory.

However, the crops of Irish Cobbler obtained, even with the best of care and spraying, have been disappointing from the standpoint of final yield of tubers. As a rule this has not equalled the average production for the same variety in the better potato producing sections of the State and at first this was attributed to the fact that the central part of the state is frequently subject to a period of mid-summer drought which is seldom the case in the more favored potato regions of the north, which also have the advantage of a soil of greater water-holding capacity. This is no doubt a contributing factor but it is by no means the primary cause of the low yields as the following discussion will show.

The crops for the past two seasons were much below the average, although the appearance of the fields in each case to the casual observer was most promising up till a few weeks before this variety would normally reach maturity. In fact an experienced farmer on seeing the 1913 field early in August stated that it was the best appearing field of Cobblers which he had seen that year.

In 1912 nothing wrong was noted with the plants until the tops suddenly died late in August following a period of dry weather. Our attention was not called to this field until the plants were practically all dead, and when examined there was considerable evidence of flea-beetle injury and some early blight

caused by *Alternaria solani*. Although the field had been well sprayed with bordeaux mixture it was thought that the early dying of the tops might be the combined results of the factors mentioned. While the possibility of some below ground trouble was suggested Rhizoctonia was not considered.

When dug it was found that the tubers produced on the field in question averaged small and that many of them showed varying amounts of Rhizoctonia sclerotia upon their surfaces. However, neither of us had an opportunity to make a detailed examination of them. A barrel of the cleanest tubers which could be storted out were shipped to Orono to be used as seed in the greenhouse for growing plants for various experimental purposes during the winter.

Even with this selected seed it was found that when the tubers were planted in the greenhouse in pots of steam sterilized soil the sprouts frequently failed to reach the surface. Examination showed that such sprouts were usually strong and vigorous when they started but later they had either been partially or wholly cut off. Fig. 62 shows a single sprout from an uncut tuber planted in a pot of sterilized greenhouse earth. It will be noted that it is entirely cut off at the base and another, smaller lesion occurs near the apex. These lesions in such cases were brown in color and more or less covered with coarse, brownish fungous threads, apparently Rhizoctonia. Both colorless and brown threads were observed.

The stems of young potato plants grown in the greenhouse from this seed frequently showed an abundance of the fruiting or Corticium stage of the fungus. This consisted of a whitish to yellowish gray felt, sometimes rather delicate, growing up around the base of the stem. As a rule this growth extended but a short distance above the surface of the soil, but in some instances it ran up 4 or more inches on the stems and leaf petioles and lower sides of the leaf blades. Fig. 64 illustrates an instance of this kind, the lighter color of the under sides of the 3 lower leaves being due to a dense coating of the fungous threads.

Lesions similar to those described later as occurring below ground on plants in the field were, in some instances, found on plants in the greenhouse. Frequently plants were noted which produced apaprently healthy and normal tops, except there was

a tendency to form tuber-like outgrowths in the axils of the leaves and branches, particularly the lower ones. Examination showed that the fungus had attacked the tuber-bearing branches of the stem below ground and cut them off before or soon after the tubers had set. This resulted in stimulating the plant to produce tubers or tuber-like outgrowths close to the surface or above ground. Fig. 68 shows the base of such a plant grown in a 10-inch flower pot.

Field Studies and Observations.

The behavior of plants in the greenhouse, even when grown from samples of the cleanest tubers produced on the field of Irish Cobblers in 1912, furnished a clue to the cause of the difficulty that season. Accordingly about two acres of the original field was replanted in 1913 with seed tubers produced on the same land the year before, in order to provide an opportunity to study conditions with regard to the crop throughout the summer. The seed tubers were treated with formaldehyde for scab the same as had been done in 1912. In fact an effort was made to have conditions as nearly like those of the previous season as possible except that the crop was being planted the second time on the same land.

Brown lesions of various sizes began to appear on the sprouts below ground soon after they started from the seed-pieces However, the injury did not begin soon enough or was not severe enough to prevent many of the sprouts reaching the surface. About the same time Mr. C. A. Day discovered a field of potatoes in the eastern part of Washington County where the same disease occurred. Fig. 63 is a reproduction of a photograph of a potato seed-piece found on this field by Mr. Day. This seed-piece had 3 sprouts and when received one was entirely killed and half of it gone, another was practically dead, and a third so badly injured that it would never reach the surface of the ground.

Early in July on the field at Highmoor Farm, the plants averaged 6 or 8 inches high after having been covered twice in cultivation. As a whole they appeared strong and healthy above ground, but one or two per cent of them extended but slightly or at the outside not over two or three inches above the hills made by the cultivator and horse hoe. Except that they were

much below the average in size some of these plants were normal in general characteristics, but many of them had begun to show some evidence of disease in that they were slightly yellowish in color or at least lighter green than normally, often having the beginning of a rossette appearance of the leaves. Frequently these might readily pass from outward appearances for plants suffering from an early attack of blackleg.

An examination of such plants showed that their stems were invariably diseased below ground. These stems which at first had been kept covered as fast or faster than they grew, by the method of cultivation or hilling, had blanched so that they were nearly perfectly white. As a result the lesions produced by the fungus stood out in marked contrast on this background. Frequently, even though the crown of leaves on the shoot appeared green, the stem would be so nearly cut off that it would be impossible to remove the plant from the row without having it break off. Figs. 65 and 66 illustrate the appearance of some of the plants at this stage. Other instances were found where one or more shoots from a seed-piece would reach the surface of the soil before becoming badly diseased while other sprouts from the same seed-piece had been killed back entirely soon after they were put forth. In this connection it may be mentioned that several bags of tubers produced on the field in 1913, after having stood in a warm cellar for some time, were examined by the writers in the spring of 1914. At this time the tubers bore sprouts from two to six inches long. A considerable per cent of these sprouts showed lesions similar to those observed on shoots in the soil the year before and in many instances the sprouts had been entirely killed. Both in the field and in the sacks the lesions on the shoots and sprouts were plentifully covered with the threads of the Rhizoctonia fungus which could be made out readily by the aid of a small hand lens. As a rule the healthy shoots and sprouts did not show the presence of these threads upon their surfaces. However, cases were observed in the field, much more frequently on the Green Mountain than on the Irish Cobbler and more especially on plants which showed the Corticium stage above where the filaments of the fungus grew up over the parts below ground without any apparent injury to them.

Plants attacked by Rhizoctonia at the stage described above may be readily distinguished from those affected by blackleg when they are dug up. The latter always show inky-black discolorations of the stem and the disease always starts at the bottom at its junction with the seed-piece and works upward through the stem. In the case of the Rhizoctonia trouble the diseased areas are brown in color, may occur anywhere on the stem below ground, and work from the surface inward. In later stages, where the attacks of Rhizoctonia have not been sufficiently severe to cause the early death of the plant a large part of the surface of the diseased stems below ground may become browned.

About the middle of July a large number of hills, so selected as to give as accurate sample as possible of the entire field, were uncovered in an endeavor to estimate the per centage of plants affected at that time. Fully 50 per cent showed the slightly sunken, brown lesions, overrun with Rhizoctonia threads, varying in size from a mere dot to those which covered from two-thirds to three-fourths of the under-ground surfaces of the stems.

A similar examination was made on August 4, taking care that a different but equally representative lot of plants was selected. By careful estimate 91 per cent of the stems showed evidence of the attacks of the Rhizoctonia fungus below ground. (Only about 17 per cent of the Green Mountain plants on an adjoining portion of the same field at this time showed evidence of similar lesions below ground. Here the attacks were not serious and apparently the damage was slight. The latter conclusion was confirmed when the crop was dug). At this time the plants were large and the tops nearly covered the ground. The gaps made by the previous death of the more severely attacked plants were entirely obscured by the growth of the others. To the average observer this looked like a healthy and exceedingly promising potato field. A careful inspection revealed the fact that slightly abnormal plants, showing a clustering of the leaves or a suggestion of a rosette effect were by no means uncommon.

In many instances the stems gave evidence of partial recovery as the plants grew older, the lesions appeared to be healed, showing simply a dark, russeted surface. In more severe

cases, but not severe enough to cause the death of the entire shoot, side branches were thrown out below the severed portion of the stem which, on reaching the surface, developed into normal tops. How deceptive such plants may be with regard to the parts below ground is well shown in Fig. 67. One of the stalks, at least, the tops of which were removed before photographing appeared strong and vigorous, but such a hill could produce no merchantable potatoes.

The evidence obtained at this second examination of the parts below ground indicated that the fungus had little effect on the older and more woody portions of the stems. As the plants grew older it confined its attacks to the younger and more succulent parts, particularly the young, tuber-bearing stolons. Many instances were observed where these stolons were killed and the young tubers cut off from the parent stem almost as soon as formed, or before they had attained any material size. Frequently cases were found where the disease spread back along the stolons and attacked the young tubers.

Regarding the ability of the potato Rhizoctonia to attack healthy plants Gloyer makes the following statement:* "That a wound appears to be necessary for the fungus to enter the tissue is suggested by Clinton's observations. He has found the 'inconspicuous grayish mealy growth' of the Corticium or fruiting stage on the stalks of the potatoes near the surface of the ground, and no injury was done to the stem at that point." After looking up Clinton's article the writers feel that Gloyer has misinterpreted Clinton's meaning and has drawn an inference which was not intended. The Corticium stage occurs above the surface of the ground and so far as we have observed is never associated with a stem injury at that point. In fact all injuries of the stem which we have attributed to Rhizoctonia have occurred below ground. Plants showing the Corticium stage were numerous on the field in question in August 1913 and the same thing was frequently observed in the greenhouse, either on plants from infected tubers planted in steam sterilized soil or on those from clean seed in sterilized soil and the soil later infected either directly or indirectly through attempts to inoculate parts of the plants with pure cultures of the fungus.

*l. c. page 419.

We have found that potato stems showing the Corticium stage usually, but by no means always, present some evidence of at least old lesions somewhere on the parts below ground. We have some reason for thinking that the Corticium stage may occur with considerable regularity on the stems of the more resistent varieties of potatoes without any evidence of injury. This, however, in no way weakens the contention that the fungus may be and is, under certain soil conditions and with certain varieties of potatoes, an active and very injurious parasite.

During the latter part of August the potatoes on the field under consideration began to take on an appearance similar to normal ripening and this developed with considerable rapidity so that by September 8 all the plants were dead. Different parts of the field had been sprayed differently and a portion was only sprayed with an insecticide to kill the potato beetles. The strip which received no fungicide lived nearly as long as one which had been sprayed with bordeaux mixture every 10 days or two weeks after about the first of July, using 4 spray nozzles per row and applying over 200 gallons per acre at each application. Hence the early death of the tops could in no way be attributed to attacks of leaf diseases. Moreover, the adjoining field of Green Mountains, which showed a much smaller percentage of plants attacked by Rhizoctonia, and none of these severely, remained green till frost came a month or more later.

The crop of Irish Cobblers was harvested as soon as possible after the tops died and at this time a careful study was made of the effects of the fungus upon the tubers. The most striking characteristic to be noted by the casual observer was the abnormal number of small potatoes produced. Hills were frequently found where the yield was similar to that shown in Fig. 69. Apparently tubers of all sizes, varying from those just formed to those weighing half a pound or more were cut off from the main stem by the fungus. As has already been stated, in many cases the fungus followed along the tuber bearing branches of the stem and attacked the young potatoes themselves.

The appearance of such tubers was very characteristic. The lesions were at the basal ends and always surrounded the point of attachment of the tuber with the stolon. In mild cases there was simply a browning of the surface closely resembling the

beginning of late blight or Phytophthora decay. This browning varied from a circle around the stem a centimeter or less in diameter to a large, discolored area covering the entire basal end of the tuber. The lesions were dry in nature, and in the more advanced stages brownish black in color, and more or less covered with Rhizoctonia filaments. The fungus appeared to be entirely superficial. As far as could be judged by microscopical examinations it did not penetrate beneath the skin to any extent. Occasionally discolored streaks following the line of the vascular bundles penetrated the flesh for a short distance but not trace of fungus mycelium could be found in them

A much more serious or advanced form of the injury of the stem end of the tuber was of frequent occurrence. On such cases after the branch stem is killed back to its junction with the tuber there begins a progressive degeneration or necrosis of the tissues of the latter from this point in all directions, forming deep cavities, sometimes two or three centimeters in diameter and extending a like distance into the flesh of the potato. This is well shown in Fig. 70. Here again the fungus does not penetrate deeply into the tissues. The interior of the cavity is lined with a dark, brown colored material which appears to be made up of interwoven masses of Rhizoctonia filaments and the remains of dead cell walls which show more or less corky developments, mixed with large quantities of free starch, which latter appears to be entirely unchanged. This form of the disease need not be confused with the decay of the stem end of the tuber caused by the blackleg organism.

The fungus appeared to be able to attack tubers independent of infection spreading from the stem. The lesions thus produced may be divided roughly into 3 different groups, two of which, and possibly all 3, are stages of the same thing. One of these is characterized by a pronounced russeting of the skin over areas of varying dimensions, leading into a corky development somewhat resembling common potato scab. The potato may largely recover from these attacks, the corky layer slough off, or be easily rubbed off, leaving slight oval depressions covered by healthy skin which had formed beneath the cork. These resemble quite closely the healed wounds on tubers which have been eaten by white grubs.

The second form of injury no doubt is a more severe stage of the first. In this the surface of the potato becomes diseased over large areas and growth on the surface is checked. The tension of the expanding tissues beneath ruptures the surface, eventually forming large cracks. These cracks enlarge as the potato grows and the fungus spreads over the tissues thus exposed and doubtless assists in enlarging and deepening them. Finally the potato becomes badly deformed and misshapen. Specimens of this form of the disease which were not especially common are shown in Fig. 71.

Still another form of the disease starts, apparently, from the lenticels. A critical examination of potatoes from a large number of sources, including those from other states, has convinced the writers that it is fairly common. Ordinarily this is an oval pit from 3 to 5 millimeters in diameter as shown in Figs. 72 and 73. It usually contains a mixture of corky remains of dead cell walls, free starch and Rhizoctonia filaments. This pitting was first noted in making a critical examination of a large number of different samples of potatoes received from different parts of the country as illustrating forms of potato scab, particularly abnormal types, in the localities from which they came.

Potatoes affected in this way and received from Nebraska and Wisconsin were planted in the greenhouse in pots of sterilized soil and the crop produced later showed different stages of the formation of the pits and the close association of Rhizoctonia with them. The young tubers showed small holes, apparently formed at the lenticels and largely filled with Rhizoctonia filaments. The tissues lining the pits were dark brown and water-soaked in appearance. Pure cultures of Rhizoctonia were obtained from the pits in the young tubers produced in the greenhouse. This, however, was previous to undertaking most of the work here recorded, particularly the greenhouse studies described in a later section.

Potatoes from the field under consideration frequently showed the pitting in various stages of development at harvest time. A study of the development of these pits, as shown by these different stages, showed plainly that they were not of insect origin. The beginning of a pit was indicated in tubers at harvest time by a slight circular browning in the region of the

lenticel. Microscopic examination of these spots, as small as they could be detected on the surface, invariably showed them to be made up of brown, collapsed cell walls and free starch with Rhizoctonia filaments running through the mass.

As the diseased area increases it becomes slightly depressed and brown in color. Usually the margin is somewhat more sunken, forming a sharp boundary line between the healthy and affected tissue. Occasionally diseased areas like this will reach the size of from two to five millimeters in diameter without any other superficial change. More frequently the tissues surrounding the lenticel begin to shrink away, leaving an opening in the center of the diseased area. This may widen out into a broad, shallow pit or if the disease penetrates any depth into the flesh it may develop into a canal leading from the center of the affected area on the surface. Such canals are popularly supposed by the farmers to be the work of wire worms or some other animal pest, but the canals are quite different from those made by wire worms.

A distinct wall of rather firm texture exists at the junction of the diseased and healthy tissue. This is firm enough so that when the tubers have been dug a few weeks if the point of a knife is placed under one edge the entire diseased area can be removed occasionally intact, leaving simply a clean pit in the healthy tissues. When the tubers are boiled the firmness of this lining of the pits or canals is still more apparent for they readily pull out and remain firmly attached to the skin when the later is removed.

Rolfs (12) mentions that the Rhizoctonia stage produces two kinds of mycelium, one light and one dark. The latter, he says, develops deeper in the tissues, is more actively parasitic and frequently produces a wet rot of the stem in old seed tubers. We have observed no wet rot or decay of potato plant parts whatever that we could attribute to Rhizoctonia. However, it should be noted that our observations were made under quite different soil conditions. Rolfs was working in the irrigated districts of Colorado, and attributed much of the trouble to over-watering, resulting in the soil becoming wet and soggy. The land on which our most careful field observations were made was a well-drained loam with some mixture of sand. At no time during this season till after the crop was harvested did

this field suffer from an excess of moisture, but, on the other hand, the moisture supply was deficient during a good part of July and August.

Greenhouse Experiments.

Mention has already been made of certain results secured in the greenhouse. The details of this work were mostly carried out by the junior writer but the observations were carefully checked by both of us. While these experiments are not as extended in some instances as might be wished, they do in a large measure confirm and extend the observations made in the field. Their chief value lies in the fact that they were conducted under the control conditions and that all inoculation experiments of growing plants and other tests, the nature of which made this precaution necessary, were carried on in pots of soil that had been thoroughly sterilized with steam under pressure of at least 20 pounds. In growing plants for inoculation experiments seed tubers were used which showed no evidence of Rhizoctonia on their surfaces, but as a further precaution were disinfected before planting.

Soil inoculation. Three series of pots containing a dozen or more in all were inoculated by burying just beneath each seed tuber small sclerotia or masses of fungous threads from pure cultures of Rhizoctonia. In no case did the fungus seriously attack the young plants or young tubers but numerous sclerotia were found on the latter when harvested. In a similar experiment described later and designed to test the effect of lime on the soil more positive results were obtained both with limed and unlimed soils. In the last mentioned test the more recently isolated culture of the fungus appeared to be more virulent. It is possible that in the experiments described above the strain used had been so long in culture that it had lost its virulence.

Inoculation of young, growing tubers. Young, growing tubers on plants in pots were inoculated with pure cultures in several instances. In some cases the surfaces of the tubers were first injured by pricking with a sterilized needle and in others small masses of the fungus mycelium were simply laid against the uninjured skin. Regardless of the manner of inoculation all plants inoculated in this way developed cases of

Rhizoctonia injury similar to that observed in the field, including typical lesions on the stems below ground and on the basal ends of the tubers.

About a month after the plants came up large clusters of small tubers could be seen just at the surfaces of the pots and in one case aerial tubers were formed in the axils of the leaves to a considerable height. It is of interest to note that this particular plant was inoculated without any injury to the stem or tuber. Check plants, the tubers of which were both punctured and untouched, remained healthy.

Inoculation of young, living potato stems. On account of limited space in the greenhouse only 3 pots were used in this experiment. When the young plants had reached the height of from one to one and one-half inches above the soil in the pots they were uncovered to their junction with the seed-piece and small particles of pure cultures of Rhizoctonia were applied to the surface of the base of the shoot, after which the stem was carefully recovered with soil. After two months the plants were dug up and examined. One was apparently healthy while the others showed the characteristic clusters of numerous, small tubers close to the stem at or near the surface of the soil. One of these showed the typical brown lesions on the stem below the surface.

Planting diseased tubers in sterilized soil. Whenever diseased tubers or those showing Rhizoctonia sclerotia were planted in sterilized pots of soil the fungus practically always appeared on the growing plant or tubers in some form or other. In such instances tubers bearing sclerotia were produced almost invariably. Stem lesions, clusters of little potatoes near the surfaces of the pots with or without browning of the surface of the stem end of the young tubers or other injury usually occurred. Less frequently, though by no means uncommonly, the Corticium or fruiting stage of the fungus appeared on the plants in the greenhouse.

Attempts were made on a small scale to determine if particular forms of the disease could be transmitted to the crop. That there was a possibility of this was indicated by the results obtained when the tubers from Nebraska and Wisconsin were planted. In one instance a badly pitted tuber of the type already described on page — was planted in one pot and in

another, one which was a typical specimen showing the decay or necrosis at the stem end with more or less cracking of the surface. The plants were dug up and examined about 4 months after planting. The tubers produced in each case were small, deformed and grouped in clusters close around the stem, largely above the surface, with some of the aerial tubers or tuber like outgrowths in the axils of the leaves and branches. The plant obtained from the pitted tuber was the less severely attacked of the two. In both cases the surfaces of the young tubers showed the characteristic browning and necrosis at the stem end, but no pitting or cracking was observed.

Three tubers of a long, slender, purple-skin variety of potatoes, variety unknown, but locally known as "Blacks" were obtained in Lewiston at the meeting of the Maine Seed Improvement Society in December, 1913. These were covered with pits filled with Rhizoctonia threads and dead tissue. These tubers were cut into 3 pieces and planted, making 9 pots in all. When the plants were mature there was no evidence of pitting on the crop produced, but many of the tubers were covered with Rhizoctonia sclerotia.

It will be seen, therefore, that what little experimental evidence we have been able to secure by planting pitted tubers or other tubers affected with Rhizoctonia, except in the case of the tubers obtained from Nebraska and Wisconsin, fails to support the assumption that Rhizoctonia is the cause of the pitting. However, it must be remembered that the character of the soil and the conditions under which the potatoes were grown in the greenhouse in the experimental tests were quite different from those where this form of the disease was observed in the field. Moreover the appearance of the pitting only in the presence of other injuries plainly due to Rhizoctonia would seem to indicate that this fungus is in some way directly or indirectly the cause of it. In the field, as has already been described, the formation of a pit could be traced in various stages from its beginning at a lenticel infected with a few threads of the fungus. At the same time it is recognized that the presence of considerable quantities of Rhizoctonia filaments constantly associated with the pits is by no means conclusive evidence that it is the primary cause of their formation. In this connection the experiments described in the following section are of interest.

Inoculation of tubers after digging. The writers have frequently observed dead, spongy areas beneath spots of the so-called common potato scab, extending in some distance from the surface. These spots varied from light to dark brown and Rhizoctonia filaments were constantly observed in microscopical mounts of the diseased tissues. Quite recently a large quantity of potato tubers, obtained from many different localities in the State of Maine, have been examined for various tuber diseases. Several cases were observed where a dry, spongy rot had developed over half an inch under the apparently uninjured skin. Many of these tubers were plainly affected with the dry rot caused by Phytophthora. However, when portions of the decayed tissue showing the other type of rot were removed from the interior of these spots, under aseptic conditions, and placed in plates of potato agar pure cultures of Rhizoctonia developed in 4 out of 6 instances.

In order to test the ability of the fungus to attack potato tubers after they had been removed from the soil, 10 clean, sound, healthy tubers about two inches in diameter were thoroughly washed, wet with full strength hydrogen peroxide for about 3 minutes, well rinsed in sterilized water and then treated as follows. Slight punctures were made on one side of each of 5 tubers with a sterilized needle and small masses of the fungus from pure cultures were laid on the surface over the punctures. Check punctures were made on the opposite side of each tuber to which nothing was applied. Five other tubers were inoculated in the same way except that the material was simply laid over a lenticel without puncturing the skin. The potatoes were then placed in a covered jar without providing additional moisture.

In 3 days a distinct, discolored and somewhat sunken area could be seen around a part of the punctures to which the fungus had been applied. At the end of one week one of these discolored areas around a puncture had attained a diameter of 6 millimeters. In two weeks this was only slightly larger, two others were somewhat over 3, while a fourth was about two millimeters in diameter. The surface of the diseased area was smooth, somewhat sunken with a slight ridge at the junction with the healthy skin. The latter surrounding the sunken spots was somewhat puckered, due to the shrinking of the tissues

beneath. The fifth inoculated puncture developed no decay. These and the other inoculated tubers were later placed in a moist chamber but no more injury developed. No decay or discoloration appeared on the check punctures or where the fungus was placed on the surfaces over lenticels.

We have, therefore, been unable to present any conclusive evidence that Rhizoctonia produces a true decay of stored or growing potatoes. However, on the latter in the soil after the tubers had been cut off from the parent stem a distinct necrosis of the surface which works slowly inward, often producing deep cavities in the basal end is by no means uncommon in severe attacks of the disease.

Experiments with germicides and disinfectants. Field experiments with germicides and disinfectants both upon soil and seed are now under way. The present discussion will, however, be confined to certain rather limited greenhouse experiments. A review of the previous work on formaldehyde and corrosive sublimate as a means of disinfecting seed tubers for Rhizoctonia has already been given and it has been shown that data obtained to date indicate that corrosive sublimate is the more effective of the two. Our own experience in using sterilized soil in the greenhouse indicates that formaldehyde is of some value but even under the best of conditions was not always effective.

In one lot of 40 ten-inch pots of soil sterilized for two hours at 20 pounds steam pressure, planted with formaldehyde disinfected potatoes which had been first thoroughly washed and a large percentage of the sclerotia removed, the crop produced in two of these pots showed Rhizoctonia sclerotia on their surfaces. In another case out of 25 pots one plant developed the Corticium stage of the fungus on the stem.

Six tubers badly covered with sclerotia were selected and planted in sterilized soil after first disinfecting 3 of them with formaldehyde in the usual manner. In both lots bad cases of the disease developed. The yield consisted exclusively of little potatoes, close to the surface and covered with sclerotia. One plant from each lot of disinfected and undisinfected tubers showed typical stem lesions below ground and one plant from each series produced the Corticium or fruiting stage above ground.

In another trial formaldehyde was much more effective. In this test 6 tubers badly covered with the sclerotia and 6 badly

pitted were used. Three of each lot were disinfected with formaldehyde before planting in the pots of sterilized soil. The untreated tubers in each case produced potatoes covered with sclerotia, some of them seriously deformed, some russeted and a part showed the "little potato" characteristics of the disease. The disinfected tubers produced a crop nearly free from sclerotia and free from other characteristics of the disease except for some slight russeting of the tubers.

A number of different tests were made where a considerable number of medium sized sclerotia were removed from the surface of potatoes and soaked for one hour in 1 to 1,000 and 1 to 2,000 corrosive sublimate and 1 to 240 and 1 to 480 of 40 per cent formaldehyde. In no case did any of these sclerotia germinate on being transferred to plates of potato agar after first being rinsed in distilled water, while untreated sclerotia soaked in pure water for an equal length of time grew vigorously in every instance.

Lime has been recommended for treating soil for Rhizoctonia but this was not found to be successful by Rolfs. To test this in the greenhouse under control conditions 12 pots of sterilized soil were planted with clean tubers. Lime was added to 6 of them at the rate of 3,000 pounds per acre. Previous to planting a mass of the fungus from a pure culture was placed in the soil in each plot just below the seed tuber. Two different strains of Rhizoctonia were used, one isolated the year before and one recently obtained.

Two of the tubers in the lime pots failed to grow and entirely decayed. The remainder produced a crop no better than that where the lime had not been applied. In all cases the new tubers were small, deformed, blackened or browned at the stem end, and more or less russeted. The potatoes were more seriously affected where the more recently isolated strain of the fungus was introduced into the pots.

Economic Importance of the Rhizoctonia Disease of Potatoes.

A large part of the foregoing discussion has been based upon observations made on one field with one variety of potatoes. Also most of the greenhouse experiments were made with

the same strain of Irish Cobblers produced on the field in question during two different seasons. If the disease occurred in this State with equal severity generally, especially in the sections largely given over to potato raising, the growers would have long since gone out of business and Maine would not hold the position which it now has as a potato producing State. However, this does not mean that what we have described is necessarily an isolated case, although it is undoubtedly more severe than the average. The writers predict that a more thorough study of the situation with regard to Rhizoctonia in New England and other parts of the country will show that it is by no means a negligible factor as a cause of potato diseases in the United States.

By the nature of its attacks Rhizoctonia produces a most insidious type of potato disease. In cases like the one described not enough plants are killed outright before they reach the surface to excite suspicion on account of the missing hills. The one or two per cent of plants which early in the summer are seen to be much under average size are accounted for as due to "weak stock" or it is explained that these are the plants where the seed-pieces fell with the eye down. Except to a critical observer the majority of the plants may appear normal and unless a period of dry weather occurs they may look reasonably healthy and vigorous nearly or quite to the average time of harvest, when the owner discovers for the first time that something is wrong.

While no other case has been seen where the disease was so common and widespread as on the field at Highmoor Farm during the summer of 1913, it has been found to some extent in quite a percentage of the fields of Irish Cobblers which have been examined in the central and southern parts of the State during the past two seasons. Judging from yet too limited observations upon which to base definite conclusions the disease does not occur as generally or in so severe a form in Aroostook County as in some sections farther south. Observations made and specimens collected by Mr. C. A. Day and Mr. M. D. Jones, in charge of farm demonstration work for the College of Agriculture in Washington and Penobscot Counties, would seem to indicate that it is widespread and common in some parts of the State and is no doubt an important factor in cutting down the

yields of Irish Cobblers in this section. It is well known that yields of Irish Cobblers are frequently disappointing farther west in the central part of the State, where good crops of Green Mountains and certain other late varieties are secured without difficulty. No doubt climatic conditions have something to do with this but there is every reason to believe that Rhizoctonia contributes its share in bringing about these undesirable results the same as it did at Highmoor Farm, which is located in the same section.

That there is considerable difference in the resistance of different varieties of potatoes to the disease and possibly a difference in the resistance of different strains of the same variety is indicated by our somewhat limited observations upon this phase of the subject. Just what varieties are the most susceptible and what are the most resistant remain to be determined. That soil conditions are important factors with reference to the virulence of the attacks of the fungus seems probable but just what these conditions are is also unknown.

Preventive Measures.

The main object of the present publication is to prove that Rhizoctonia is a real, though previously largely unrecognized, cause of potato disease in the East, that at times with certain varieties and under certain soil conditions it may become of considerable economic importance, and to point out the prominent characteristics by which it may be recognized. While field and greenhouse experiments are being conducted along the line of preventive measures we have secured no results which add to the knowledge of this phase of the subject. Any advice as to control measures then must be based upon previous work or consist of recommendations of a more or less general or empirical nature.

The first thing to do is to determine by examination of germinating and growing plants whether or not the fungus, which is common in most potato soils, at least where potatoes have been grown for any length of time, actually causes any material injury to the varieties grown, under the soil conditions which exist. If not it may be ignored unless one is growing seed potatoes for a trade which requires seed free from the fungus. If the latter is the case or trouble is experienced from the disease,

a supply of seed tubers which show no evidence of sclerotia of the fungus on their surfaces should be secured, if possible. For a seed disinfectant before planting, corrosive sublimate should be used. This has certain disadvantages but it appears to be the most effective agent for destroying the fungus upon the tubers that has yet been found and it is equally as efficient as formaldehyde for treating potatoes for scab. No doubt the fungus lives over year after year in the soil without the presence of a crop of potatoes for it readily grows as a saprophyte and is a parasite on a wide range of unrelated hosts. However, rotation of crops and allowing as long a time to elapse as possible between successive crops of potatoes is desirable. Planting crops of potatoes on the same land two years or more in succession should not be practiced.

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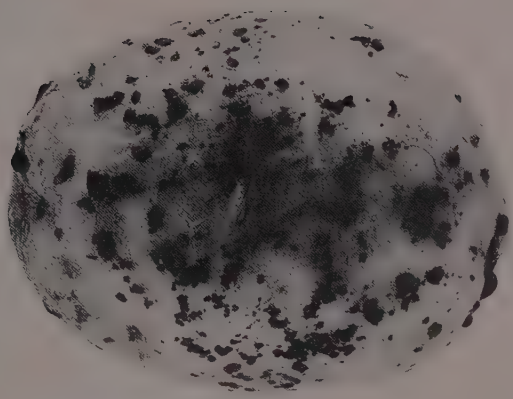

FIG. 61. Potato tuber showing "black scurf" or sclerotia of Rhizoctonia.

FIG. 62. Potato tuber planted in the greenhouse. The base of the single sprout is entirely destroyed and a second lesion has appeared near the apex.

FIG. 63. Potato seed-piece the sprouts of which have been killed by Rhizoctonia before reaching the surface of the ground.

FIG. 64. Young potato plant upon which the Corticium stage of the fungus occurred. Note the growth on the under sides of the 3 lower leaves as well as upon the base of the stem.

FIG. 65. Young potato plant showing lesions produced on the stem below ground early in the season.

FIG. 66. A more advanced and a more severe case of the same form of Rhizoctonia stem-injury as shown in figure 65.

FIG. 66. A more advanced and a more severe case of the same form of Rhizoctonia stem-injury as shown in figure 65.

FIG. 67. Base of potato plant showing lateral branching and partial recovery following the killing of the top of the original sprout early in the season. The tops, which were removed before photographing, were nearly normal in size but the plant would produce no merchantable tubers.

FIG. 68. Clusters of tubers formed at the surface of the ground after the parts below had been badly injured by Rhizoctonia.

FIG. 69. A typical hill of potatoes showing the "little potato disease."

FIG. 70. Necrosis of the stem end of the tuber following bad attacks of Rhizoctonia on the parent stem.

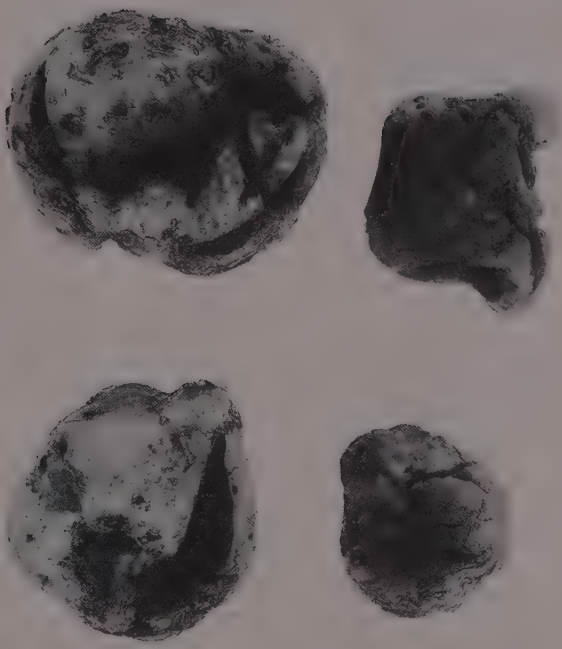

FIG. 71. Splitting and cracking of the tubers following severe attacks of Rhizoctonia.

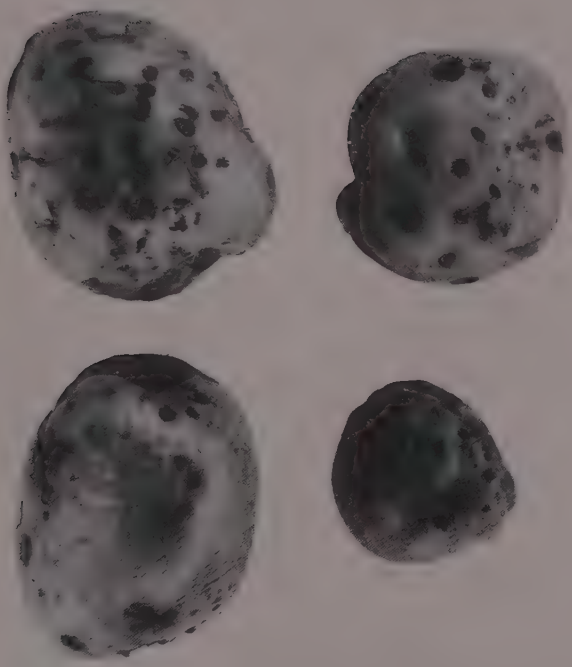

FIG. 72. Pitting of the tubers which is frequently associated with bad cases of Rhizoctonia injury on other parts of the plant.

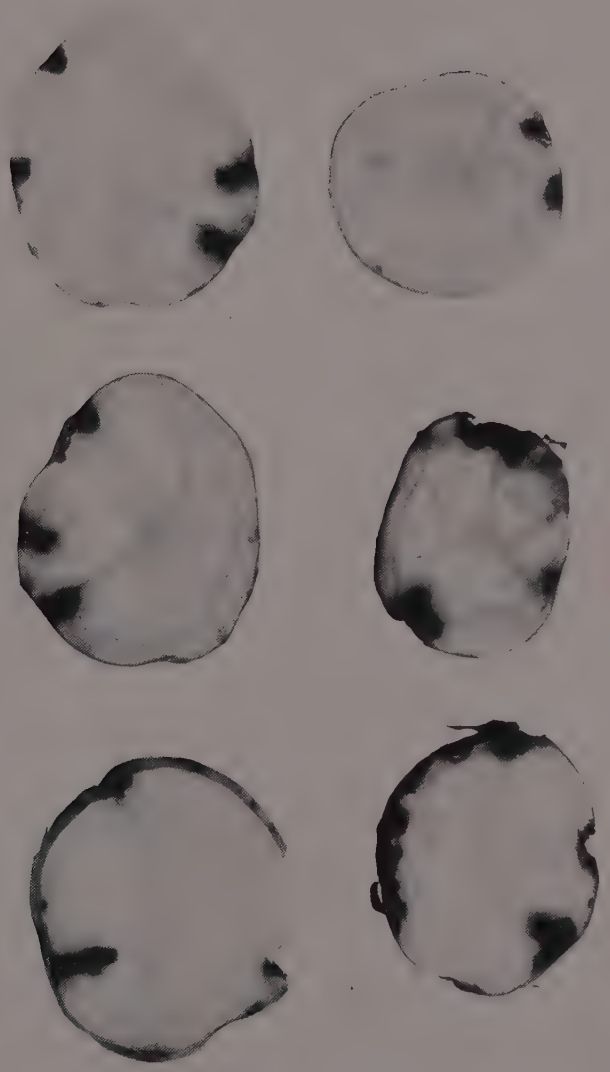

FIG. 73. Cross sections of tubers through the pits.